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Wind availability and its potentials for electricity generation in Tafila, Jordan

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Abstract

In this paper, long-term wind speed and direction available at Tafila, Jordan (1990–2000) have been studied and analyzed. The average wind speed was found to be equal to 4.4 m s^{-1}, which indicates the suitability—to a certain extent—of using only small size wind parks to produce electricity to fulfill the deficient electric power during the peak hours. The wind direction was found so variant, which makes it unique for installation of wind parks due to limited area of Tafila. The extractable power was found to vary from 27.36 to 34 W m^{-2}.

Keywords: Wind speed; Wind direction; Wind power; Electricity generation; Jordan

Contents

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1. Introduction

Jordan has a little indigenous energy resources and is almost fully dependent on crude oil imported from neighboring Arab oil producing countries [1,2]. Efforts to overcome the unsustained energy demand in Jordan include optimization of energy use in all sectors, demand management, and also use of alternative energy sources [3]. The latter includes renewable energies, particularly solar and wind energies which are promising [4–8]. Among the renewable energy technologies, the generation of mechanical and electric power by wind machines has emerged as an economically viable and cost-effective option [9,10]. Therefore, the government has begun to pay more attention to the use of wind energy in rural areas in particular as a cost-effective solution to assist in electricity generation, water pumping and irrigation. These activities have stimulated the scientific and research communities in Jordan to launch a serious series of investigations of wind energy potentials in the country.

This paper examines the plausibility of utilizing wind power in Tafila after collection of long-term records (10 years, 1990–2000) of wind speed and directions.

Tafila is a small city, which is located in the southern part of Jordan (187 km from the capital Amman), and connected to the electric grid. However, the demand on electricity is much greater than the available electric power supply [11]. Therefore, seeking a supplement power to support the conventional source of energy is of great importance.

2. Data collection

The wind speed and directions in Tafila for the period from 1990 to 2000 (10 years) were obtained from the Jordanian Meteorological Department. The station (Al-Hasan station) is located at Tafila, which is located in the south of Jordan (187 km south of Amman—the capital of Jordan).

The data have been averaged over the 10 year period. Data are recorded every 10 min and then averaged on hourly basis, where further averages are then made.

3. Results and discussion

Fig. 1 shows the wind speed duration histogram. It depicts that the most durable observed wind speed in Tafila derived from the long-term average data (1990–2000) is 3 m s^{-1} and was observed 23 times, followed by 4 m s^{-1}, which was observed 16 times, 2 m s^{-1} which was observed 13 times, 5 m s^{-1} which was observed 11 times, 6 m s^{-1} which was observed nine times, 7 m s^{-1} which was observed six times, 8 and 9 m s^{-1} which were observed five times, 10 m s^{-1} which was observed three times, 11 m s^{-1} which was observed two times, 12 and 13 m s^{-1} were observed one time. The remaining wind speeds occurred less than once throughout the 100 time observation period.

Fig. 2 illustrates the wind speed frequency. It reveals that the wind speed 5 m s^{-1} has the highest frequency during the year, i.e. 15.89%, followed by 6 m s^{-1}

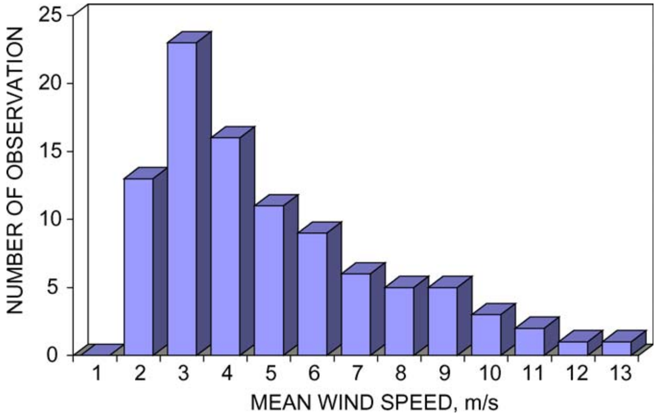

Fig. 1. Wind speed duration histogram for the observation period from 1990 to 2000 at Al-Hasan station, Tafila.

(15.45%), 4 m s^{-1} (14.07%), 7 m s^{-1} (13.17%), 3 m s^{-1} (10.31%), 8 m s^{-1} (9.92%), and 9 m s^{-1} (6.63%). Since the required wind speed for a wind park is above 3 m s^{-1}, so the wind turbines will run during the year by 93%.

The long-term monthly variation of wind speed is presented in Fig. 3. It is obvious that the highest wind speed in a month occurred in February (6.24 m s^{-1}), followed by 5.82 m s^{-1} in March, which are the winter months in Tafila, when the demand on electricity is the highest among other seasons of the year [11]. The least windy month was October (3.048 m s^{-1}) followed by September (3.1 m s^{-1}).

Fig. 4 exhibits the mean hourly variation of the long-term recorded wind speed from 1990 to 2000. It shows that during the day the wind is very active at 12:00 GMT (5.09 m s^{-1}). This time of the day is considered as the peak hour in Tafila, when the demand on electricity is the highest during the day [11]. This is of course

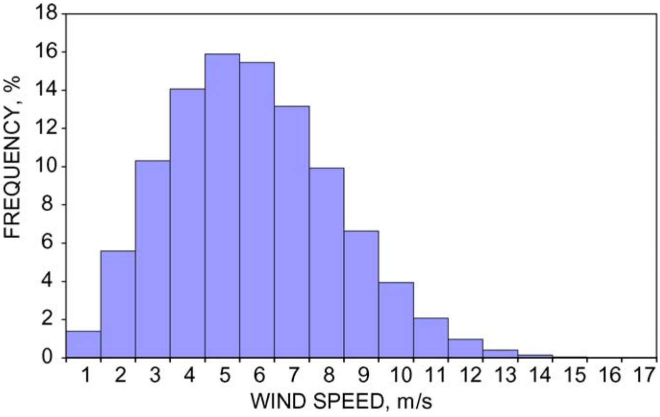

Fig. 2. Wind speed frequency recorded for the average data from 1990 to 2000 at Al-Hasan station, Tafila.

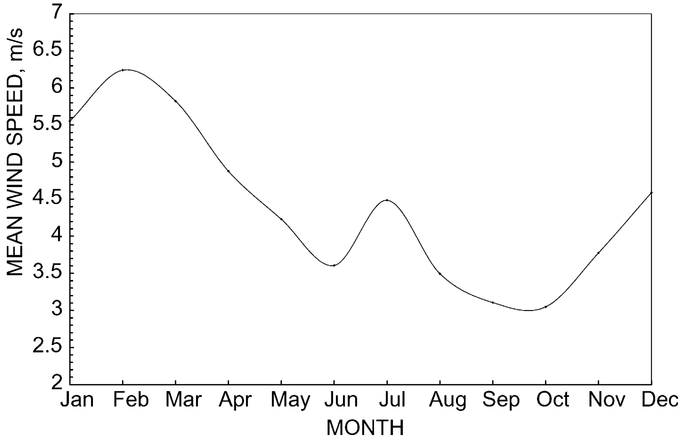

Fig. 3. Mean monthly variation of the recorded wind speed data from 1990 to 2000 at Al-Hasan station, Tafila.

in favour of utilizing wind energy for the supplement of the deficient electric power at this time of the day. At 24:00 GMT, the wind becomes inactive. At 9:00 and 17:00 GMT, the wind speed has approximately the same values. This behavior is nearly the same each month. This is obvious from Fig. 5.

The average wind speed (v)can be calculated precisely by the following formula [12]

$$v = \sum_i (v_i \times T_i) \quad (\mathrm{m\ s^{-1}}) \tag{1}$$

where T_i is the number of hours corresponding to the ith speed interval divided by the total number of hours; v_i is the mid point wind speed for the ith interval.

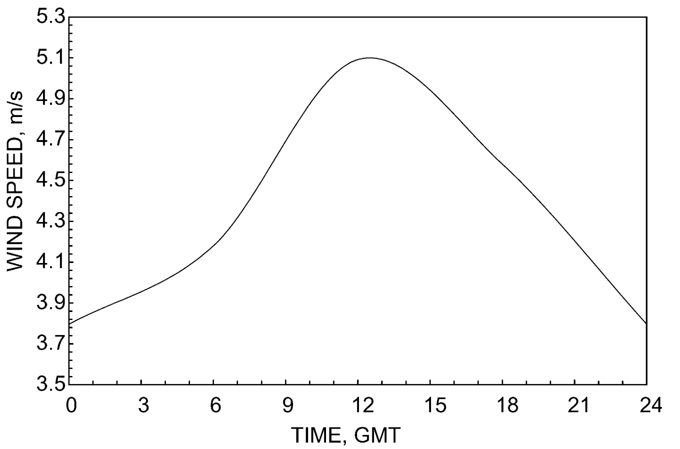

Fig. 4. Mean hourly variation of the recorded wind speed data from 1990 to 2000 at Al-Hasan station, Tafila.

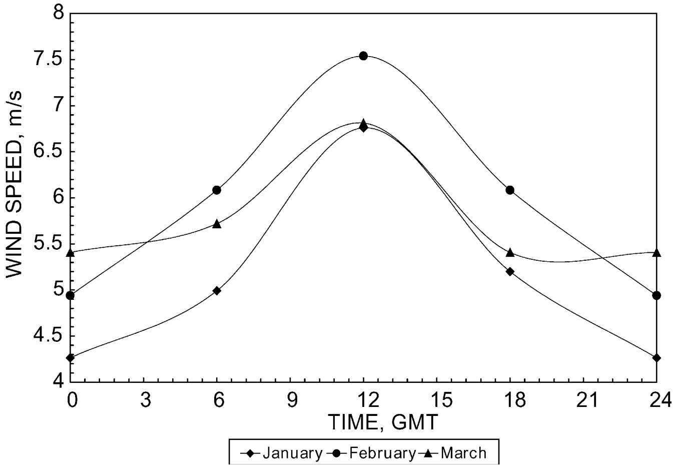

Fig. 5. Seasonal hourly variation of the recorded wind speed data from 1990 to 2000 at Al-Hasan station, Tafila.

Therefore, the total available power (P_a) in a cross-sectional area perpendicular to the wind stream moving at the speed v is calculated as follows:

$$P_a = 0.5\rho \sum_i \left(v_i^3 \times T_i\right) \quad (\mathrm{W\ m^{-2}}) \tag{2}$$

where ρ is the air density (kg m^{-3}).

The total extractable power (P_e), i.e. the power that can be extracted from the wind speed, depends on the available wind power and on the operating characteristics of the wind turbine [13]:

$$P_e = 0.5\rho C_p \sum_i \left(v_i^3 \times T_i\right) \quad (\mathrm{W\ m^{-2}}) \tag{3}$$

where c_p is the power coefficient ($c_p = 0.59$ for ideal rotor).

The extractable wind power can also be calculated from the kinetic energy (K.E.) in a parcel of air of mass moving at speed v in the x direction [14]:

$$\mathrm{K.E.} = 0.5mv^2 = 0.5\rho \mathrm{A}v^2 \quad (\mathrm{J}) \tag{4}$$

where A is the cross-sectional area.

The wind power (P_w) is the time derivative of the kinetic energy [15]:

$$P_w = \frac{\partial}{\partial t}(\mathrm{K.E.}) = 0.5\rho \mathrm{A}v^2 \frac{\partial x}{\partial t} = 0.5\rho \mathrm{A}v^3 \quad (\mathrm{W}) \tag{5}$$

As $\rho = 3.485P/T$, where P is the pressure (kPa) and T is the temperature (K). Therefore:

$$P_w = 0.5\left[3.485\frac{P}{T}\right]\mathrm{A}v^3 \quad (\mathrm{W}) \tag{6}$$

Taking $P = 87.5$ kPa and $T = 289.5$ K for Tafila climate the wind power becomes:

$$P_{\mathrm{w}} = 0.5266\ \mathrm{A}v^3 \quad (\mathrm{W}) \tag{7}$$

When producing Betz coefficient ($16/27 = 0.593$), where the maximum power is being transferred from the tube of air to the turbine as mechanical power extracted, then Eq. (7) becomes:

$$P_{\mathrm{w}} = 0.312v^3 \quad (\mathrm{W}) \tag{8}$$

Using Eq. (1), we found that $v = 4.41$ m s^{-1}, and the total extractable power P_{e} (Eq. (3)) becomes 27.63 W m^{-2}. When using Eq. (7), P_{e} becomes 34 W m^{-2}, since $v = 4.78$ m s^{-1} with prevailing wind direction SWWW.

The above-mentioned results clearly show that utilization of wind energy is not suitable in Tafila because the wind potential is not high enough (typical $v > 7$ m s^{-1}). The cost of 1 kW h, under such conditions, may reach no less than 4 Jordanian dinars (JD), including maintenance, and other economic factors (1 JD = 1.5 US$). The only advantage of using wind energy in Tafila is that by installing small size wind turbines to support the deficiency in electricity supply at daytime peak hours.

Study of wind directions in Tafila showed that the wind blows 50% of the time from SWWW followed by 15% from the west, 12% from NWWW, 8% from SWW, and the same percentage from SSSE. Most of the low wind speed (up to 5 m s^{-1}) occurs in different directions. This is in favour of using small size wind generators [16,17].

4. Conclusions

The available wind power in Tafila is not so sufficient to reach an economic status. The initial cost per kW h will be no less than 4 JD, including the maintenance, and other economic considerations. Therefore, the best application of wind energy in Tafila is for low power consumption places. The wind power cannot depend on much to supplement the energy deficiency at day and night in Tafila. This is because the wind speed is below the threshold limit to be economically viable ($v > 7$ m s^{-1}). However, small size wind park generators can be connected to the main electric grid, and utilized to support the deficiency of electricity during the peak hours.

References

[1] Akash B, Mohsen M. Energy analysis of Jordan's urban residential sector. Energy 1999;24(9):823–31.

[2] Jaber J, Probert S, Williams P. Evaluation of oil yield from Jordanian oil shales. Energy 1999;24(9):761–81.

[3] Badran O. Study in industrial applications of solar energy and the range of its utilization in Jordan. Renewable Energy 2001;24(3–4):485–90.

[4] Habali S, Amr M, Saleh I. Wind as alternative source of energy in Jordan. Energy Conversion and Management 2001;42(3):339–57.
[5] Durisch W, Keller J, Bulgheroni W, Keller L, Fricker H. Solar irradiation measurements in Jordan and comparisons with California and Alpine data. Applied Energy 1995;52(2–3):111–24.
[6] Mamlook R, Akash B, Nijmeh S. Fuzzy sets programming to perform evaluation of solar systems in Jordan. Energy Conversion and Management 2001;42(14):1717–26.
[7] Hrayshat E. Wind energy in Jordan: current status and future potential. Proceedings of World Renewable Energy Congress-VII. Oxford: Elsevier Science; 2002.
[8] Mohsen M, Akash B. Potentials of wind energy development for water pumping in Jordan. Renewable Energy 1998;14(1–4):441–6.
[9] Hammad M. Photovoltaic, wind and diesel; a cost comparative study of water pumping options in Jordan. Energy Policy 1995;23(8):723–6.
[10] Mamlook R, Akash B, Mohsen M. A neuro-fuzzy program approach for evaluating electric power generation systems. Energy 2001;26(6):619–32.
[11] Jordanian National Electric Power Company. Annual Report. Amman: NEPCO Press; 2001.
[12] Burton T, Sharpe D, Jenkins N, Bossanyi E. Wind energy handbook. Chichester: John Wiley and Sons Inc; 2001.
[13] Anani A, Zuamot S, Jibril Z. Evaluation of wind energy as a power generation source in a selected site in Jordan. Solar and Wind Technology 1988;5(1):67–74.
[14] Culp A. Principles of energy conversion. New York: McGraw Hill; 1991.
[15] Alnaser W, Al-Karaghouli A. Wind availability and its power utility for electricity production in Bahrain. Renewable Energy 2000;21(2):247–54.
[16] Manwell J, Gowan J, Rogers A. Wind energy explained: theory, design and application. Chichester: John Wiley and Sons Inc; 2002.
[17] Gipe P, Perez K. Wind energy basics: a guide to small and micro wind systems. Chelsea Green Pub Co; 1999.